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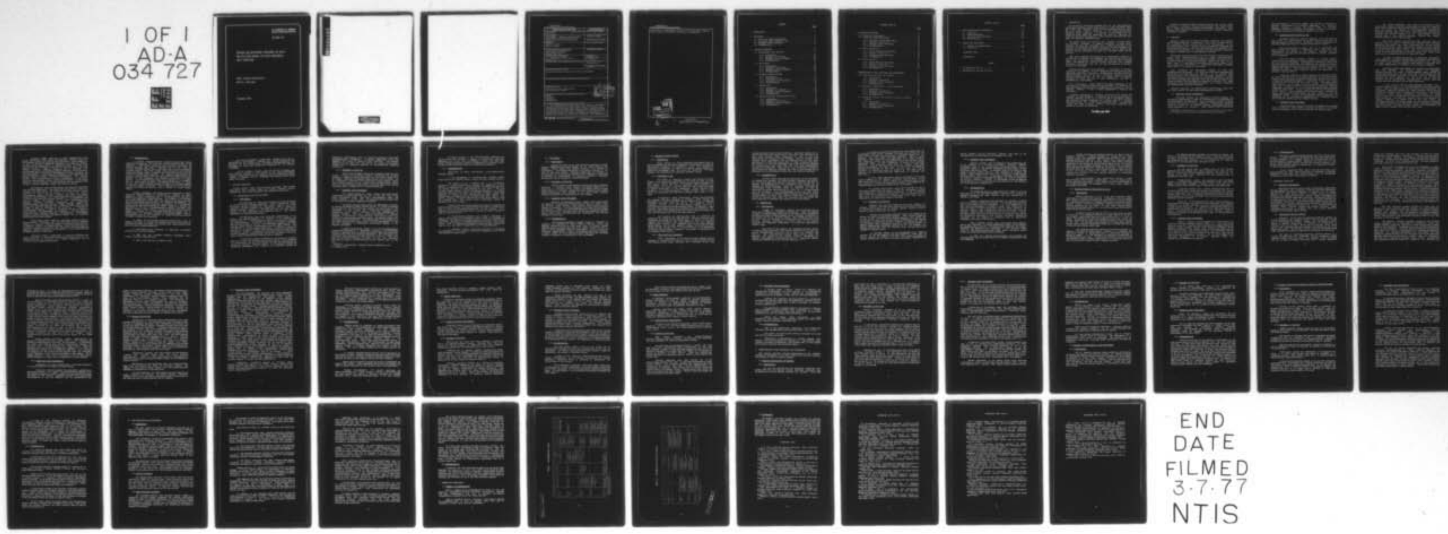

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RESEARCH AND DEVELOPMENT ASSESSMENT ON SAFETY AND POLLUTION CONTROL FOR OUTER CONTINENTAL SHELF OPERATIONS

HARRY DIAMOND LABORATORIES
ADELPHI, MARYLAND

DECEMBER 1976

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An investigation has been made of the research, development, and data gathering that would provide some of the tools, both information and hardware, that could be used to increase safety and decrease pollution hazards associated with offshore oil and gas exploration and production. Methods have been identified for reducing the dangers to which both workers and structures are exposed during drilling, subsurface production, and transportation

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operations. These dangers include fire and explosion, asphyxiation, blowout, pollution, and unsafe rig conditions.

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1. INTRODUCTION

As the need for energy has increased, the oil and gas exploration and recovery operations taking place on the U.S. outer continental shelf (OCS) also have increased. Along with this increased activity, there has been greater public awareness of the safety and pollution aspects of those operations. In addition to this concern, the U.S. Geological Survey (USGS) has recognized the need for improving the safety and antipollution aspects of those offshore activities that fall under its regulatory responsibilities.

The problem cited as the cause of most accidents involving safety and pollution incidents in offshore operations is human error. Therefore, the USGS has recognized that a complete evaluation of the potential for decreasing the number and severity of these accidents must consider not only technology and its capabilities, but, in addition, the need for training, motivation, and good work attitudes among the men involved.

This report summarizes the results of an investigation, sponsored by the USGS, of the research and development that would provide some of the tools, both information and hardware, that could be used to increase safety and decrease the pollution hazards associated with offshore activities. This report does not go into the questions of personnel training or motivation.

The report consists of an introduction, a discussion of five main categories, and a summary. The five categories are structures, drilling operations, subsurface production, transportation, and data collection and distribution. Each of the five categories includes one or more subjects discussed in terms of what is required, what is currently available for field use, what is under development, and what is recommended for improvements.

The investigation, whose results this report summarizes, is the first part of a continuing effort that was initiated in December 1975. The investigating team chosen had no background or expertise in the oil industry. However, it had a strong background in research and development.

To obtain a background in offshore operations in the limited time available, the team attempted to maximize use of the various types of training available, as well as to use a variety of information sources. The training included attendance for 2 weeks each at a drilling operations school and a workover and completion school. An additional 2 weeks was spent visiting offshore facilities, observing both production and drilling operations.

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Information sources included literature searches and various trade periodicals. In addition, the team visited several USGS field offices and a number of industry research and development facilities. This activity was rounded out by attendance at the 1976 Offshore Technology Conference in Houston.

2. STRUCTURES

Basically, there are two types of offshore structures: the floating and the bottom supported. As operations have moved to deeper waters, the prohibitive costs incurred due to the strengthening of the structures required have created a need to separate the wellheads from the separation stations. Thus, many new facilities have appeared in oil fields with the wellheads at the mudline and the production operations on either a floating rig or bottom-supported platform.

Exploratory drilling is done mainly from floating structures such as barges, ships, semisubmersibles, and ice islands. Some exploratory drilling also is done from bottom-supported jackups and shallow-water, artificial islands.[1*] Barge-type artificial islands are used in ice areas (also in delta areas) as containers with sand and gravel fill. Other islands are constructed by using subsea berms made of sandbags before sand fill is placed in the interior.

Most production and hydrocarbon transfer is done from bottom-supported structures. Of these, the gravity and pile-supported structures are the mainstay of the industry. As the industry moves further offshore, new structures and structural systems are being considered to offset the high cost of conventional structures. To this end, the bottom-supported compliant tower, the tension leg platform with subsea wellheads, the semisubmersible production platform with subsea wellheads, and the subsea production template with surface separation and storage tanker are being developed.

Workover operations are accomplished by using jackups, barge rigs, and, more recently, the more stable semisubmersible platform.

2.1 Structural Safety Requirements

Structural designs are evaluated by insurance companies and engineering organizations in terms of the operations to be performed and the environmental considerations. Once the structure is built to specifications and installed on site, a number of safety-related operations should be carried out to minimize hazards. These operations may be either preventative or detective. Known hazards should be prevented,

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**Literature references will be listed only at the end of this report (p. 46) because of the extensive survey made during this study.*

such as corrosion of structural members and fasteners, scouring of footings, overstressing of structural components, and collision. Existing corrosion, cracking, and erosion should be detected. Subsurface corrosion and corrosion at the water's surface are a couple of the most persistent and difficult problems to deal with.

2.2 Structural Safety Systems in Use

Structural safety for surface components out of the range of wave action is usually assured by periodic visual inspections and periodic painting. Some x-ray or ultrasonic inspections are used, but only after some other visual or audible indication of a problem.

Collision prevention is largely left up to helicopters and ships moving in the vicinity of stationary rigs. Radar and radio communications are adequate in most weather, including fog and precipitation, although then the detection range is greatly diminished due to scattering.

Below the water's surface, corrosion is a major problem. Corrosion is an electrochemical process, which is controlled through the use of sacrificial components. These components are made of metals that are more chemically active than the metals they are intended to protect. Depleted components periodically are inspected and replaced where diving capabilities permit. More recently, the problem of the erosion of platform footings has been minimized through the application of protective concrete shells.

Cracks and corrosion on subsea components are detected visually by divers, although x-ray and ultrasonic detection is used occasionally. Present diving techniques range from conventional and saturation diving to manned and unmanned submersibles. Conventional diving can be done routinely to 300 ft and to 600 ft for ½hr or less. Saturation diving ($He-O_2$ mixture) can be made to 1000 ft; however, long decompression times (up to 10 days) decrease its usefulness.[2] An unmanned, tethered, submersible manipulator is in use in the experimental Exxon Submerged Production System (SPS). Diving capabilities with the SPS manipulator are to 2000 ft, using television and sensor data links. Provision for manned observation during operations has been included in the SPS manipulator design. Diving from maneuverable manned submersibles is limited to 1000 ft, with acoustic communication for untethered vehicles and electrical communication for tethered vehicles.

2.3 Equipment under Development

Hazard prevention research for structural members has increased due to the need for going further offshore and dealing with the more hostile environments of the Gulf of Alaska and the Atlantic coast.

For surface components, new paints and coatings are being investigated. Special attention is being applied to the wave region of the structure where both wind and water effects are always a problem and where ice effects are present in lower-temperature environments. Bituminous coatings, tapes, and mastics have shown[3] good resistance to corrosion and erosion; however, the new fusion-bonded, thin-film coatings seem to have superior resistance, although some cathodic bonding problems are still being studied.

Hull-stress warning devices[4] have been used for years on merchant ships to predict overstress and to analyze effects of chosen maneuvers. Such devices are being investigated for use on offshore mobile drilling units. These rigs generally operate in either a moving or a drilling mode and thus require a dual dynamic response analysis. In May 1976, the Ocean Express jackup sank (13 people died), and the Penrod 60 jackup sustained severe structural damage when caught while under tow in a surprise storm off the Texas Gulf coast.

The Army[5] is supporting research in atmospheric propagation, object signature, and object imaging using submillimeter maser waves in low-visibility environments, including fog and precipitation. This type of system might be of use offshore in bad weather to supplement radar and radio communications in navigation and in collision avoidance.

Recently, several environmental and structural loading studies have been completed. The National Oceanic and Atmospheric Administration and the Bureau of Land Management jointly studied[6] the Alaskan continental shelf for the seismic and ice environments and some bottom-loading effects. Wave data on period, spectral analysis, and amplitude are being developed for the North Sea by both the industry[7] and the classification organizations.[8] Platform structural stresses have been analyzed[9] and are being researched.

In the Gulf of Mexico, Exxon installed in November 1975 a 1/5-scale compliant tower[10] to test this deep-water production platform design. Exxon is taking data on wind and waves, deck acceleration and inclination, structural stresses, and guyline tensions. Exxon has also organized an industry effort to obtain total force data on a space-frame structure.[11] Earlier Conoco measurements (unpublished) on single vertical piles have been used by the industry in the design of Gulf of Mexico structures. The Exxon new structure was to be in operation for 6 months beginning in October 1976 and will help define the total-base shear and overturning moment on the structure, the spatial and temporal distribution of hydrodynamic forces, interference phenomena (such as in groups of conductor pipes), forces on inclined members, and impact forces on members above the mean water level.

Structural member inspection is being researched by using forced oscillations from either high-frequency acoustic sources or low-frequency oscillations from wind and wave action. Both systems can be used for surface or subsurface inspections for cracks and defects. Acoustic testing applies mainly to components above the water, since connection to the necessary structures is relatively easy. Below the surface, difficult cleaning operations may be necessary with high-pressure water or sand blasting before components can be installed. The main problems[12] with acoustic measurements are noise rejection and data interpretation. Noise rejection techniques include determining the optimum frequency window, rise-time discrimination, and spectral analysis. Data interpretation involves determination of the signal source by characterizing various materials and defects. A more recent approach[12] involves analysis of source emissions over an extended period of time in terms of amplitude, energy, and frequency spectra.

Low-frequency wind- and wave-driven oscillations of structures also are being researched.[13,14] This measurement has particular appeal for inspection for defects below the surface of the water, because it might eliminate the need for men and sensors to go below the surface. Accelerometers measure structural response from which the natural frequencies are determined. The lowest frequencies would represent the structure's rigid body oscillations; harmonics of the fundamental also would be evident. The highest (10- to 20-Hz) frequencies would represent individual component oscillations, and intermediate frequencies would indicate coupling between component members. Any shift in this frequency spectrum, over a period of time, would indicate a change in mass or stiffness of the structure. A reduction in stiffness would indicate a possible structural failure or change in bottom support. This measurement can be applied[13,14] on pile-supported structures where spectral stability, instrumentation environmental hardness, analysis techniques, and spectral changes due to structural modifications have been studied.

Other subsea hazard detection techniques require divers or subsea vehicles. Techniques that have found application are magnetic particle or electrical potential testing for external cracks and sonic or gamma-ray testing for internal defects. Severe winds and waves, in addition to subsurface turbulence, make application of these techniques hazardous. Pretest cleaning of the structure is also a difficult and hazardous operation at any depth.

Although a diver's capabilities of operation deteriorate for depths below 2000 ft, deep diving capabilities are down to 5000 ft for saturation diving, to 15,000 ft for a manned submersible, and to 20,000 ft for an unmanned submersible.[2]

2.4 Recommendations

A reliable computer-operated structural-stress alarm system should be developed for use on the many diverse structures used for OCS operations. Overstressed components are particularly hazardous for floating drilling rigs both in operation and in tow. Once the critical structural members were identified, they could be instrumented to detect loading. The alarm system would consist of a set of strain gauges with digital output, a computer with stress-analysis program, and a visual or audible alarm indicator. The computer program would take data for a given period of time and then predict the maximum load to be expected for the subsequent time interval (longer than the sample period). If the maximum design stress were predicted to be exceeded, then an alarm would be given. The sampling period would be fixed, but the time between samples should be variable to allow more sampling in hazardous loading situations. Further capabilities could provide an analysis for stress-load reduction and a printed or visual display readout.

Various techniques and systems are being developed to detect structural component failure or deterioration. However, the basic approach to subsea inspections has to be determined for the USGS to fulfill its inspection responsibilities. For example, it is preferred to dc subsea inspections from above the surface of the water, provided that the technologies yield accurate and repeatable measurements. The study of wind- and wave-driven natural oscillations of pile-supported structures has shown great promise for subsea inspection. However, the applicability has yet to be demonstrated on gravity structures with changing liquid storage levels, to drilling platforms with day-to-day changes in loading, or to structures whose mass is changing due to marine fouling or underwater flooding of structural members. Thus, a comprehensive study of the inspection of subsea structures should be initiated to answer these questions:

a. Where are the principal structural hazard areas, such as bending at the base of risers and platform legs, scour at the base of platforms and subsea components, and corrosion and marine growth at the water line and on subsea components?

b. What should be the frequency of inspections for various structures and structural members?

c. What are the available measuring techniques, their accuracy, and their repeatability?

d. What is the best way to inspect a site?

The Army is developing submillimeter radiation for use in low-visibility environments. Research will include frequencies that penetrate fog and precipitation. Propagation measurements should be encouraged at these more penetrating frequencies for the offshore environment.

For the offshore Atlantic coast and the Gulf of Alaska, more data should be obtained on the effects of the local environmental loading of structures and on the effects of gravity structures on bottom loading. If necessary, the U.S. Government and industry jointly should gather these data.

3. DRILLING OPERATIONS

In this section, there are five topics considered. These include measurements while drilling (MWD), gas sensing, equipment testing, computer use, and a blowout-preventer (BOP) pressure-relief valve.

3.1 Measurements while Drilling (MWD)

3.1.1 Requirements

The usefulness of being able to obtain data from the bottom of the well during drilling operations, without interrupting those operations, has been recognized for many years. However, no proven technology reliably provides this capability.[15] Such a system has numerous specific benefits in providing for safer and less costly drilling of both exploration and production wells. This section emphasizes the safety-related benefits.

Any MWD system must have three basic capabilities: (1) to measure the downhole parameters of interest; (2) to telemeter the resulting data to a surface receiver; and (3) to receive and interpret the telemetered data. In addition, it would be very useful to transmit data from the surface to the bit. This additional capability would make possible surface control of sophisticated downhole safety devices, such as a BOP and a mud circulation bypass valve. In addition, it would be possible to selectively request that particular data be transmitted to the surface. Finally, the accuracy of the data received at the surface could be checked by retransmitting the data to the bottom of the hole, where signals transmitted and received could be compared.

Of the three essential capabilities, the ability to telemeter data to the surface is currently the limiting factor in the development of an MWD system. The use of bottom-hole recorders has demonstrated the ability of currently available sensors to continuously measure the bottom-hole environment.[15] For safety, it is of interest to predict the

approach of high-pressure zones to allow the execution of the proper kick-preventative procedures. A downhole temperature sensor and gamma-ray log[16] would be useful for this prediction. The downhole sensing of a kick would give the driller an earlier, more accurate warning than is currently available in this potentially dangerous situation.*

3.1.2 Equipment in Field Use

While several downhole sensors are in general field use, none provide a signal to the surface without interrupting the drilling operation or requiring special trips when the drill string length is to be changed. Similarly, no downhole safety devices (such as BOP's) can be continuously controlled from the surface to allow downhole rather than surface control of a kick. Another useful downhole safety device would be a mud-circulation bypass valve, with which heavier mud could be circulated above a clogged bit or a closed downhole BOP.

3.1.3 Equipment under Development

Four general methods are being studied that would provide transmission of precise data from one end of the well bore to the other: mud-pressure pulse, hard wire, electromagnetic waves, and acoustic methods.[15] At this time, the mud-pressure-pulse method seems to be closest to becoming commercially available.

The method currently being pursued by Schlumberger and Teleco to generate mud-pressure pulses involves the use of a valve to modulate the resistance to the flow of the mud through the drill string.[15] The advantages of this method are a relatively high-speed signal transmission (about 4000 to 5000 ft/s) and ready adaptability to existing equipment. (The only required modification to downhole equipment is the addition of a special drill collar sub near the bit that contains the pressure-pulse generating valve, the downhole sensors, and the related control apparatus.) The disadvantages of this method are a relatively slow data rate (from 6 to 60 s for each measurement[15,17]) and the poor reliability of mechanically moving parts exposed to the downhole environment.

A general disadvantage shared by all of the communications systems being developed is a temperature limitation. The solid-state electronic components used to control the downhole system are inherently limited to less than 400°F operating temperature. This translates to an operational depth limitation of from 15,000 to 18,000 ft. While most wells are not drilled this deep, for those that are, this limitation would mean a return to current practices for the deepest part of the well.

**Letter to Shareholders, Raymond Precision Industries, Inc., (16 January 1976).*

A possible solution to the high-temperature problem is the use of fluidic logic devices to replace the solid-state electronic components now in use. Past environmental testing has shown that fluidic devices can operate reliably at temperatures in excess of 1000°F and can be made relatively immune to vibrational environments.[18]

3.1.4 Recommendations

Three areas of effort could benefit the mud-pressure-pulse telemetry system.

a. The development of a surface-to-bit telemetry system would allow use of downhole safety, control, and data checking devices.

The ability to use a downhole BOP is of considerable importance. It would introduce an entirely new capability in well control. As identified by a hazards analysis of offshore operations by the General Electric Co. under contract to the USGS,[19] the only critical safety hazard in current oil-field operations is a blowout around the outside of the casing. No available equipment allows rapid regaining of control of the well once such an event occurs. The availability of a downhole BOP not only would allow well control to be rapidly regained, but would allow options to the driller that he does not currently have. This control could significantly reduce the probability of such a blowout.

Placing a mud-circulation bypass valve above the downhole BOP would allow the driller to circulate weighted mud above a closed BOP so that it could be deactivated without loss of well control. Also, weighted mud could be circulated above a clogged bit before tripping to repair or replace the bit.

b. The destructive effects of the downhole environment on exposed moving parts in the telemetry system could be decreased or eliminated. The currently used mud-pulsing valve could be replaced with such fluidic components as a feedback amplifier oscillator and a vortex triode. Such a system would probably increase the data transmission rate by one or two orders of magnitude (up to 50 measurements/s).

c. Miniature fluidic logic devices should be investigated for replacement of the solid-state electronic components now in use for high-temperature applications.

3.2 Gas Sensing

3.2.1 Requirements

Because the threat of gas leaks around the platform is always present, combustible gas sensing systems are at various points on the platform. These systems must operate reliably in a variety of environments. The required sensitivity of the system depends on the type of gas being sensed. (Hydrogen sulfide must be detected in concentrations of a few parts per million, while combustible gases must be detected at concentrations of tenths of a percent.) A desirable system would require infrequent or easy maintenance.

3.2.2 Equipment in Field Use

Various electronic gas detection devices are used on offshore platforms. In general, these devices have adequate sensitivity to detect the required levels of gas. However, the output signals of these highly sensitive electronic systems drift when subjected to the rugged offshore environment. This drifting of the output signal requires frequent maintenance and recalibration of these systems.

3.2.3 Equipment under Development

Recently, no-moving-part fluidic sensors have demonstrated the capability of sensing gas concentrations as small as several parts per million. These devices, which produce fluid pressure and flow signals as functions of various properties of the gas, such as density and viscosity, contain no electronics and have no moving parts except for the fluid itself. Therefore, these devices are extremely rugged and should require much less maintenance and recalibration than devices currently in field use.

3.2.4 Recommendations

A three-stage development program should be initiated to determine the usefulness of fluidic sensors offshore. First, the expected sensitivities of the three basic types of fluidic sensors available should be studied for each of the gases of interest in the oil field. Second, breadboard models of these sensors should be built for laboratory demonstration. Finally, if breadboard tests were favorable, a sensor system for field testing should be fabricated and evaluated offshore to determine its usefulness in that environment.

3.3 Equipment Testing Program

3.3.1 Requirements

Proper testing of various components and systems helps to identify problems with particular components and systems and to schedule their routine inspection and maintenance. Also, once problems are identified, the component or system in question can be replaced, or research and development needs can easily be identified. For these benefits, test procedures must adequately represent reality.

3.3.2 Procedures in Use

One method of obtaining accurate test results on various devices is to record their performance in the field, as done to some extent by all offshore operators. There are two important drawbacks to this method. First, the lack of systematic data collection and interpretation can easily bias the results so that a device can appear to operate excellently in one application, while operating only marginally in a second application. Second, problems with a given device are recognized only after those problems have arisen in the field.

In response to these shortcomings, several test procedures and programs have been developed by industry. These include the development of a safety-valve-test facility sponsored by the American Petroleum Institute (API) and run by the Southwest Research Institute,[20] as well as a BOP valve-testing program that is a joint-industry-sponsored program managed by Exxon. In addition to these programs, some safety-device test procedures have been adopted by API. Also, individual device manufacturers test their products in-house to be sure that the devices meet their own specifications.

This response by industry shows that it recognizes the problem and is moving in the right direction. However, there are still limitations associated with the current level of effort. First, while standard test procedures have been adopted for the most important safety-related devices, many components still have not been examined. Second, because the various suppliers present test results on their devices in such diverse ways, it is very difficult, if not impossible, to directly compare similar components with respect to operational and environmental specifications.

3.3.3 Other Practical Procedures

These shortcomings of the current testing programs could be overcome by extending this effort to cover all safety-related devices. This extension would entail designing test conditions so that they

accurately reflect various field conditions. Such tests could be run to closely duplicate field conditions for "real-time" test correlation, or they could reflect field conditions in such a way that "accelerated-life" testing could be performed. This last approach would simulate device performance over an extended period of time while requiring only a relatively short period of time to acquire the data. The validity of such test procedures could be ascertained by comparing the resulting data with field data that have been systematically collected and interpreted. These proven test procedures can then be used to point out potential problems and also to help evaluate device performance in new environments before field test data are available.

3.3.4 Recommendations

The USGS should encourage and participate in the development of standard test programs for safety-related components and systems. For any test program to be effective, the test procedures used must be adequate and standardized so that independent test results can be compared in a meaningful manner. Next, all available Government and non-Government test facilities should be identified so that the requirement to provide new facilities to carry out a testing program would be minimized. Once this groundwork is done, the USGS should encourage the testing of safety-related components and systems to obtain the data needed to derive the benefits listed above. As these test results are obtained, they should be correlated with data gained from field experience to determine the validity of the test results.

3.4 Computer Use

3.4.1 Requirements

A number of significant benefits can be obtained from the direct use of computers in offshore oil operations. First, the computer can help to eliminate human error both by providing a better man-machine interface for safety-related equipment and by providing information to the operator for use in decision making. This information input could be in the form of providing the latest data on the condition of the drilling operation, predicting the future state of the drilling operation, and suggesting alternatives to the operator, especially if problems arise.

Other uses for the computer are automated functional testing of safety-related components[21] and automatic generation of the input for various data-gathering activities now or soon to be offshore (see sect. 6). The data-gathering function would greatly reduce the paperwork load falling on the operator offshore. Eventually, the computer will probably be used more and more in a closed-loop manner, controlling somewhat the entire drilling operation.[22,23]

To provide the predictive capabilities, the computer must use a mathematical model of the processes that take place in the well. On these models are based the well-control techniques employed by the operator. Many such models have been formulated. Some are quite simplistic, while others are very complicated. It is common practice that simplistic models are continuously refined into the more exact, complicated models as more information is gained from operating experience. This information might show, for example, that under certain circumstances the model being used is not able to adequately represent the behavior of the well. At this time, if the model deficiency is significant enough to warrant it, the model can be improved (and most likely made more complicated) to eliminate that deficiency.

For this model improvement, data on the behavior of the well must be compared to the behavior calculated from the model. If the model being considered is fairly simple, it is relatively easy to make this comparison. As the model becomes more complex, this comparison can become excessively difficult without the aid of a computer.

If a computer were already being used to provide the type of operational support mentioned above, it would be reasonable to extend its capabilities to that of automatic evaluation of the mathematical model being used to represent well behavior. This evaluation, in turn, would point out deficiencies in the well model, which could then be addressed by the appropriate technical personnel.

3.4.2 Equipment in Field Use

Computers have not seen widespread use in the offshore oil industry. However, some significant future use on production facilities is indicated by Exxon's use of onshore computer control of quite a number of offshore production facilities.

Computer use on drilling platforms seems to be limited to the running of a series of independent programs. Some provide information on the current condition of the drilling operation and predict the possibility of a kick, while others suggest alternatives to the operator for avoiding or controlling the kick. However, no evidence was seen of computer output being displayed directly on the drilling console. In typical installations, specialized technicians run the computer as a separate facility away from the drilling floor and keep the driller informed of computer output.

An important aspect of any contemplated use of computers offshore is the requirement for adequate transducers. These must be able to provide the computer the data that it needs to perform the various calculations for which it has been programmed. Observations of

various offshore drilling facilities indicate that much of the instrumentation for data input to the computer is in use.

3.4.3 Equipment under Development

Improved software will be required if more advantageous use of the computer is to be made in the future. Currently, software development seems to be concentrated in two general areas. First, a significant amount of specialized programming is being written to meet individual contractors' needs. In addition, there is an effort by some groups to provide software that will take advantage of downhole MWD systems. These programs should prove very useful when the MWD systems become available (sect. 3.1). In addition to software, various groups are working to improve the mathematical models for various aspects of the drilling operation. Finally, the development of new and improved instrumentation is a continuing process that should aid in the effective use of the computer's capabilities.

3.4.4 Recommendations

The technology exists to make possible the computer use that would result in the benefits mentioned in section 3.4.1. Such use is expected eventually when these benefits have been demonstrated by systems in the field.

Computer technology would therefore be generally accepted sooner by providing demonstration systems at an earlier date than would occur at the present rate of development. It is recommended that the USGS fund the development of a computer system with capabilities of input and output of safety-related data, with an output display at the driller's console. Such a system should provide the driller with all available safety-related information that is of use to him. "Useful" information means that which would notify him of situations that require his intervention (according to some criteria previously accepted and programmed into the computer) or information that he specifically requested via an input at the console.

Such a computer system could also provide other benefits, such as the evaluation of various mathematical models of well behavior and automated data collection on safety-related components and systems, including the response to the environment of the structure itself (sect. 2). The data collected could include those required by current as well as future USGS data-collection programs.

To make this computer system feasible, the transducers and instrumentation used to provide input to the computer system would need to be improved.

Another area where the computer would be of help is that of personnel training. A system analogous to systems used to train aircraft pilots and supertanker captains could be used to help train supervisory drilling personnel. This system could simulate various drilling conditions, such as drilling through shale under controlled conditions or the reaction of the well while taking a kick. The trainee would react to the situation presented by the computer, and his reaction would appropriately affect the condition of the well. Such a training aid would allow the trainee to have realistic hands-on experience in a variety of situations, without the danger associated with allowing inexperienced personnel to make important decisions in potentially dangerous situations.

To take advantage of this training-aid concept, a study should determine what has been accomplished. If such a system exists, its use should be encouraged. If the system has not been developed, or if it needs improvement, the development of a useful model should be encouraged by the USGS.

3.5 Blowout-Preventer Pressure-Relief Valve

3.5.1 Requirements

Blowout prevention is one of the most important safety requirements in offshore well drilling. A blowout can occur in several ways. However, one mode of blowout was identified as a critical problem (a problem important enough to warrant high-priority corrective action) when the General Electric Co. performed a hazards analysis of offshore drilling operations for the USGS.[19] In this mode, formation damage caused by high-pressure buildup in the well bore allows the blowout to occur outside the well bore.

A blowout around the well bore does not occur often, but once it does occur, it is extremely difficult to regain control of the well. If a shallow, high-pressure gas zone is encountered, and if a kick is taken, the problem is to prevent the pressure buildup that causes the blowout around the well bore, while efforts are made to regain control of the well. This buildup can be prevented by allowing some formation fluids, usually shallow, high-pressure shale gas, to escape from the top of the well bore through choke lines.

The escaping fluid that relieves the well-bore pressure is, however, a pollutant and safety hazard. Therefore, it is important that this fluid release be allowed only when it is absolutely necessary to prevent a blowout. In this situation, the knowledge and experience of the driller come into play. He must decide whether to allow polluting and hazardous fluids to escape from the well at a controlled rate or to risk an uncontrolled blowout through a damaged formation.

No adequate automatic equipment is available to override the driller if he should allow the pressure buildup in the well bore to get too high. Since human error is very often cited as the cause of safety- and pollution-related incidents in OCS operations, it would be beneficial if such equipment were available for use.

3.5.2 Equipment in Field Use

All BOP stacks used to control wells in OCS drilling operations must be equipped with a choke manifold (OCS order No. 2). With it, the driller relieves excessive pressure in the well bore. The setting of the choke valve determines the back pressure that is maintained in the well bore.

Pressure-relief valves are extensively used throughout industry to prevent fluid pressures from reaching levels that would damage fluid-holding equipment. However, there is no such use of pressure relief valve for BOP's used in offshore drilling operations.

A potential problem when a surface pressure-relief valve is used with the BOP stack is that the pressure to be limited by it is not at the surface, but at the casing seat some distance below the mudline. However, this same type of problem is faced by the driller, who must decide whether or not to open the choke valve to relieve the potentially dangerous well-bore pressure.

Proper use of the pressure-relief valve requires knowing, to some degree of accuracy, the pressure at the casing seat. This pressure is equal to the surface pressure plus the pressure head between the surface and the casing seat. An estimate of this pressure head can be obtained when the density of the fluid in this upper well section is known. A worst-case value (maximum possible seat pressure) could be obtained by assuming the fluid density to be that of the mud when the kick occurred.

3.5.3 Equipment under Development

Exxon is working on the development of a downhole BOP to be used with a well-bore telemetry system (sect. 3.1). This type of BOP would go a long way toward solving the problem of preventing excessive pressure buildup without letting large amounts of formation fluids escape the well bore. This buildup could be prevented without the use of a pressure-relief valve on the BOP stack. To be effective, this BOP would have to be at or near the bottom of the well bore. Also, even if this device were successfully developed, its use would depend on the successful development of a well-bore telemetry system with surface-to-bit communication capability.

3.5.4 Recommendations

The use of a surface pressure-relief valve with the BOP stack presents a possible means of eliminating human error that could result in the occurrence of a blowout around the well-bore casing due to pressure-induced formation damage. Therefore, the feasibility of the use of a pressure-relief valve on the BOP stack should be studied. Such a study should consider possible alternatives as suggested by industry or other interested parties.

If the feasibility study should find the use of this valve worth pursuing, the USGS should encourage the development of prototype hardware for field testing and follow through with the appropriate regulations if these test results should so warrant.

4. SUBSURFACE PRODUCTION

4.1 Production Requirements

Subsurface production within today's technological capabilities excludes hydrocarbon and contaminant separation and power generation. Some preliminary gas-liquid separation is possible on one system; however, all other systems require a surface station for power generation and separation facilities. General system requirements are to receive and transfer hydrocarbon production, characterize production, provide artificial lift (such as gas or water), provide structural and environmental protection, provide remote hazard detection and control, detect pollution, provide maintenance and replacement capabilities for equipment either through the flowline (TFL) or by wireline through the wellhead, enable flowline pigging and control corrosion. These requirements are handled in different ways with varying degrees of success by the different subsea systems.

4.2 Subsurface Production Systems

Basically, the two types of subsurface production systems can be distinguished by the presence of either a wet or a dry tree. The wet tree is technologically simpler, cheaper, and serviceable by either manned or unmanned submersibles or by divers. It is more prone to corrosion than is a dry tree. The wet tree is used most often, being part of four different production systems, and proposed for use in one system under design. The dry tree is used in only one production system today, although two systems incorporate dry enclosures for servicing.

The Deep Oil Technology subsurface system[24] consists of a cluster of subsea wells and a production facility mounted on a common template located on the ocean floor. The equipment, which is designed for use in 1600 ft of water, is serviced with a manned submersible

diving bell equipped with work arms designed to make and break connections during maintenance operations. A multiplex control system is used for remote operation of equipment during normal production conditions. Production from the subsea facilities could be directed to a platform, to shore, or to a floating facility. The first commercial wells were installed in the Persian Gulf in 1972.

Exxon's SPS[25] is designed mainly for the development of larger fields. It consists of a cluster of subsea wet trees and associated production-controlling equipment (preliminary separation and pumping) mounted on a subsea template designed for application in water depths to 2000 ft. Initial production will send fluids to an adjacent platform by pipeline, where separation and subsequent transfer to shore will take place. In a later development stage, fluids will be transported by a production riser and single-point mooring from the template wellheads to a storage and separation tanker. Separated hydrocarbon fluids will then be pumped to another tanker for transport to shore. The subsea equipment is remotely controlled by an electrohydraulic control system. Pumpdown (TFL) tools are used to service the well-bore equipment, and a mechanical manipulator operated from the surface is used for maintenance operations on the subsea trees. Equipment on the structure is designed in modules so that the system can be replaced by using the manipulator. The SPS template was initially installed in 170 ft of water in the Gulf of Mexico in October 1974. To date, three wells have been drilled and completed, and flowlines have been connected between the production platform and the wellheads. No production has yet taken place. The production riser and mooring system have been built to be installed in late 1976.

The SEAL subsurface system[26] consists of a guide base for multiple wet trees, wellhead connection assembly, and 1-atm maintenance enclosure. The chamber houses well controls, monitoring devices, pumpdown (TFL) equipment, the test separator, and pigging equipment. The equipment is designed for remote operation by a supervisory control system. Field testing of the system was initiated in 1972 in the Gulf of Mexico in 250 ft of water.

The Hamilton Brothers subsurface completion and floating surface production and storage system[27] is designed for fields with marginal economic production. Mobility and early startup yield a faster return on the investment. Completions are of the wet-tree single-tubing type with TFL maintenance. A central collection manifold and production riser sends the fluids to a semisubmersible rig equipped for separation operations. The separated hydrocarbons are then pumped back down through an adjacent flowline in the production riser to the collection manifold, where they are diverted via another riser and single-point buoy mooring to a storage and transport tanker nearby. No production can take place unless the tanker is in position. All flowlines are

connected by divers. In a storm, the semisubmersible rig can shut in the wells and retrieve the production riser while the storage tanker is moved off the mooring site. This system has been installed in 300 ft of water in the North Sea and has been operating since 1975.

The Shell-Lockheed subsurface production system[28] is aimed at the development of (1) hydrocarbon fields to 3000 ft with single dry trees in a chamber and (2) a collection manifold with bottom-to-surface pumping capabilities. A diving capsule, with the ability to attach to the subsea chamber, shuttles maintenance personnel. Maintenance is carried out in a 1-atm air environment with the capsule attached to the chamber and a support ship, supplying power and life support, connected to the capsule through an umbilical line. Production testing and wireline servicing were available on the first units installed in 1972. A later version contains pumpdown (TFL) servicing either from within the chamber or from a central manifold. This central manifold would be able to test production from each station before mixing and pumping fluids to a surface separation facility. The basic functions are performed with the chamber unattended, but under a computer-based supervisory control system. All parts of the system are protected with a fail-safe electrohydraulic control system to back up remote shut-in functions. This electrohydraulic system provides control of individual valve position and indicates valve position and subsea wellhead pressure. All flowline connections are made from within the chamber. Present capabilities are limited to 2000 ft only by the design of the subsea chamber.

Vickers Oceanics (W. Wilson, private communication) has designed a subsurface production system based on the inspection and servicing considerations of the North Sea environment. It incorporates wet trees, some with and some without encapsulating chambers, TFL servicing from a central manifold, and a pump station. Additional servicing can be done on the wellheads with chambers in a 1-atm wet environment by linking up to an untethered submersible. Once pressures are equalized to 1 atm, divers can move from the 1-atm dry environment of the submersible to the 1-atm wet environment of the chamber. The wet chamber provides a safe, inert environnent in which to make repairs. Surface separation of fluids would be required as in other systems.

4.2.1 Subsurface System Requirements

Maintenance of a safe, pollution-free, serviceable operation is of prime concern in the design of subsea systems.

Diving in a 1-atm air chamber for installation operations or maintenance involves life support and communications problems. Fire and explosion detection presents problems not significantly different from those at the surface. Suppression, however, must consider both the prevention of fire and explosion and the maintenance of life

support in any manned enclosure. Life support requires approximately a 2.8-psi partial pressure of oxygen in the lungs (R. Gann, Naval Research Laboratory, private communication). But the oxygen requirements for sustaining various kinds of hydrocarbon fires are based on the mole fraction of oxygen. Thus, sustaining life and preventing fires are not mutually exclusive. The prevention of asphyxiation in these closed environments also must be considered. This prevention will require flood detectors, gas detectors, and backup life-support supplies. Initial installation operations will require a stable surface support vehicle capable of maintaining position in various wind and wave conditions and water depths. Finally, the prevention and detection of hydrocarbon pollution to the environment also must be designed into these systems for maximum effectiveness.

4.2.2 Systems in Field Use

Capabilities in diving and subsea communications have been considered in section 2.3. Fire prevention has been addressed through the use of nonflammable materials, inert atmospheres, and sensors with onboard and remote warning systems. Atmosphere inerting was first used in the SEAL subsea work enclosure.[26] A nitrogen atmosphere was used in the production section and an air atmosphere in the control section. While working in the production section, crew members wear breathing equipment, which they can attach to either a central air supply or the small portable air-supply bottle that they carry. The Shell-Lockheed system[28] also uses a nitrogen atmosphere while in service. When the system is manned, an air atmosphere is introduced or a portable breathing system is used. In the event of fire while the system is manned, nitrogen or a 1:9 mixture of Halon gas (Dupont 1301, bromotrifluoromethane) to air would replace the air atmosphere, and the mask breathing system would be used. Various types of fire detectors have been used in these subsurface chambers. Among them, the ultraviolet, photoelectric, and ionization types are most common.

Asphyxiation problems have been handled with gas detectors (chemical plus balanced bridge type) and flood detectors (photoelectric). Rescue has been aided through the incorporation of additional docking ports and safety-release systems for the submersible shuttle vehicle.[28]

The mainstay of the supply-ship fleet, the "Coastal Cruiser" type,[28] was the logical first choice for subsurface support. The addition of the four-point moving system gave this system sufficient stability in conditions up to sea state four.

Pollution detection has been handled with flow metering and volume totalizers for manifold and storage systems. Additional detection has been in the form of collectors around critical parts of wet trees and gas or liquid detectors for dry chambers.

4.2.3 Equipment under Development

For fire suppression, gas detectors and inert atmospheres are getting the most attention. Gas detectors are notorious for their constant need for recalibration (Max Lambert, USGS, private communication). They drift due to the depletion of the reactant chemicals, temperature changes, and their minimal specificity for the required gas. Quite often, the main requirement for these detectors is that they give an alarm when the hazardous gas is present, although the threshold is allowed to drift. A reliable maintenance-free detector has yet to be produced. Fire-spectra detection systems are being developed to handle the problem that spurious background signals can cause false alarms. In these systems from a combination of ultraviolet, infrared, photoelectric, ionization, and flicker-flame-rate detectors (D. Bright, National Bureau of Standards, private communication), simultaneous signals would be required before an alarm signal could be given. Not all of these detectors would be necessary, but some minimum number would be used to handle the most prevalent type of fire for an environment. Atmosphere inerting is being researched at the U.S. Army Chemical Center, National Bureau of Standards, and Naval Ship and Engineering Center. Most of the emphasis is on Halon gas, high-pressure nitrogen-oxygen atmospheres, and high-pressure fogs. Evidence suggests that long exposures to Halon gas in concentrations greater than about 10 percent have physiological side effects (Merritt Birky, National Bureau of Standards, private communication). Concentrations in excess of about 7 percent are necessary to handle class A and B fires (Merritt Birky, private communication), but class C fires require concentrations in excess of 20 percent (no longer breathable). In the presence of a thermal source or during suppression, noxious byproducts can be produced (R. Gann, private communication), so that prolonged use may not be possible. Since different criteria for the presence of oxygen are needed to breathe than to support a fire, high-pressure nitrogen-oxygen atmospheres are being researched. Air pressures below 2 atm but above 1.5 atm require no decompression and do not sustain a liquid hydrocarbon fire (R. Gann, private communication). A 3-atm pressure is required for methane-fire suppression. High-pressure fogs can suppress a fire once started, although long exposures to these fogs can suffocate workers (D. Bright, private communication).

Asphyxiation prevention research is directed toward producing reliable gas detectors and rescue systems. Backup rescue systems using surface control or self rescue (automatic seal and release) are being developed for situations in which the subsurface crew is incapacitated.[28]

New special-purpose support vehicles are being developed for offshore operations. Semisubmersible platforms for pipe laying, fire fighting (Harrisons [Clyde], Ltd., private communication), and diving are being tested (Shell Development Co., private communication). The use of submarine support vehicles also is under development (Shell Development Co., private communication) to operate down to 300 ft below the surface. Support operations could be done completely below the surface and thus avoid the surface weather.

Pollution control research is directed mainly toward the development of flowmeters with greater accuracy. Acoustic devices, using piezoelectric transducers for both the emission and detection of acoustic waves transmitted through the flowing fluids, are available with accuracies up to 10 times greater than those available with orifice meters. As an important additional advantage, some devices can be strapped to the outside of the pipe with no through-the-pipe connections necessary. (For additional information, see sect. 5.3.)

4.2.4 Recommendations

Research should be sponsored to develop alternative inert breathable gases for fire suppression with minimum physiological side effects and less noxious byproducts. An inert atmosphere, preferably nitrogen, should be maintained at all times in subsea work areas with provision for plug-in and portable air supplies. Nitrogen is preferable to air since it is cheap and completely inert. If the atmosphere is to be breathable, multiple inerting atmospheres should be studied further for injection at different times in the fire-suppression cycle. This injection would incorporate the use of Halon gas, high-pressure fogs, and high-pressure nitrogen-oxygen atmospheres. Multiple-signature fire detectors are needed to overcome spurious signals. A reliable combustible gas detector should be sponsored. This would probably require use of a sample gas cell for calibration.

A reliable hydrogen-sulfide detector and its byproducts (in the presence of water) should be sponsored since these gases are highly toxic and corrosive. A portable or plug-in breathing system would help minimize the toxic effects whenever the service area is manned.

Support-vehicle stability regulations should be established for various sea states. These regulations should take into account the types of support operation and the minimum on-site time requirements.

Various electromagnetic and optical techniques can detect hydrocarbons in a trough canopy. A survey of these techniques and some testing are needed to establish standards and minimum detection levels. Acoustical flowmeters appear to be more accurate

than other available meters or metering system; however, their reliability at sea has not been satisfactory[29] and, thus, should be investigated.

4.3 Subsea Completions

Completion operations include all procedures performed within the well bore or on the wellhead from when the producing zone is penetrated and drill-stem tested until the well is placed on production. The system includes the production tubing, the subsurface safety valve and sensors, the wellhead tree and hanger, the flowlines, the production riser, and the system-protecting structural members. Operations to service the well that do not change its mechanical condition include replacement of failed tubing, provision for pumpdown (TFL) replacement of valves, flowline pigging, provision for the injection of hydrate or corrosion inhibitors, provision for supervisory control by remote monitoring and shut in, and erosion detection.

4.3.1 Subsea Completion Requirements

Operations leading to well completion or maintenance must be done safely and with a minimum of environmental pollution. Blowout must be prevented. Hydrocarbon pollution due to erosion or corrosion of valves and flowlines must be minimized. Finally, impact protection must be provided from falling objects or anchors. Impact detection also must be developed.

4.3.2 Systems in Field Use

Both wet and dry trees have been installed to depths of 300 ft for standard production systems. Although wells have been drilled in 2000 ft of water, no completions have been attempted, indicating a possible gap in technology if not a lack of need.

Flowlines are, in general, remotely connected with either diver assistance or diver standby. Subsurface television minimizes the need for divers. The Shell-Lockheed system has connected flowlines by pulling them into the 1-atm chamber and then connecting them to the tree. Wing valves are controlled by pressure-level sensors on flowlines and by level sensors on pressure vessels.[30]

Potential pollution problems are handled by preventive maintenance. Cathodic components are placed on critical hardware to minimize corrosion. Erosion sensors are used at bends in flowlines and must be sampled periodically for maximum protection. Some components such as valve seats and sensor probes are protected from erosion by the use of shields. Cracks and pitting are detected by ultrasonic and x-ray testing. To establish minimal operational

standards, devices such as subsurface safety valves are being tested (Southwest Research Co. test facility, sponsored by API). Pollution is detected by collection troughs. Sonic sensors are being used for gas-leak detection.

Impact protection has been designed into many of the subsurface production systems. The Shell-Lockheed system shields the wellhead by placing it in a chamber shaped to minimize the effect of impact forces.[28] The Exxon SPS has a canopy over the wellhead area that not only protects the trees, but catches pollutant spills.[25] Sonic detectors are available for the detection of impacts; however, their use has been limited.

4.3.3 Equipment under Development

Increasing valve lifetime, through the use of coatings and surface treatments of valves, is an area of continuing research. Sand cutting is still a major problem and is being worked on by the suppliers. A surface laser treatment of metals has been developed to increase hardness and maintain ductility (E. M. Breinan, United Technologies Research Center, private communication). If it could be applied to the alloy steels in completion systems, this treatment could significantly reduce corrosion and erosion.

A high-sensitivity bottom-hole pressure gauge using a coaxial downhole transmission system has been developed[31] that can be used for continuous logging to determine fluid density, detect leaks downhole or at the wellhead, and measure static pressure of nonproduced reservoirs. Resolution is possible to 1 ppm at 10,000 psi with an absolute accuracy of 0.025 percent of full scale, if the temperature is accurately known.

4.3.4 Recommendations

The USGS should retain a file of the history of all safety-related equipment from the time of installation to the time of replacement. It should list the critical part, operator, reason for replacement, and duration of effective service.

A study of the effects of laser-induced changes in alloy surface characteristics on the erosion and corrosion of critical completion components should be sponsored to demonstrate the effectiveness of this process.

Data transmission techniques other than coaxial cabling may be necessary for certain completions, to retrieve downhole sensor data such as those obtainable by the high-sensitivity bottom-hole pressure gauge. One such system is the fluid-pulse fluid-turbine telemetry and power supply.[17]

Impact sensors should be developed and used on subsea trees and flowlines. An array of such sensors could help locate the position of such an impact and thus help reduce diving time and risk.

4.4 Subsea Workovers

In contrast to other remedial operations on a producing well, workover operations are made to restore or increase production. Pulling or resetting of liners, squeeze cementing, perforating, fracturing, deepening, and sidetracking are examples of workover operations that would change the mechanical condition of a well.

Workover operations may require surface support vehicles, submersible vehicles, or divers. Lighter work such as plugging, fracturing, perforating, or acidizing can be done by using either wireline or pumpdown techniques. Heavier work such as the pulling of tubing and sidetracking will require a surface derrick.

4.4.1 Subsea Workover Requirements

A listing of the workover requirements would include blowout prevention (sect. 3.5.1), fire and explosion prevention (sect. 4.2.2), diving support (sect. 4.2.2), and surface-support-vehicle stability (sect. 4.2.2).

4.4.2 Systems in Field Use

Most subsea operations use surface-controlled wireline techniques with diver support. Some pumpdown (TFL) operations have been performed, but mainly on experimental systems.

Wet trees have been repaired by divers. Surface rigs have been used where long-duration dives are necessary. In the 1-atm Shell-Lockheed chamber,[28] trees have been repaired to about 300 ft and should be repairable at any depth where the chamber can be designed to survive (at present, to about 1200 ft). Trees and flowlines are usually installed and removed by divers. Tubing is pulled mainly from surface rigs.

Wireline operations have been carried out in the Shell-Lockheed chamber[28] and also on wet-tree installations by using surface support. The following pumpdown (TFL) operations have been carried out (R. Johnston, Otis Corp., private communication): the replacements of subsurface safety valves, gas lift valves, circulating control valves, and standing valves. Sliding valves, tree valves, and tree-valve pressure have been tested, flowlines have been pigged, and scale and paraffin have been scraped.

4.4.3 Equipment under Development

A reliable remote flowline system for connection and disconnection to deep-water wet trees has yet to be demonstrated, although the Shell-Lockheed 1-atm chamber[28] has demonstrated a capability that can be applied to both wet- and dry-tree connections.

Pumpdown (TFL) operations are being extended to include sand consolidation, squeeze cementing, and perforating. Extension from 2- to 4-in. tubing operations also is being developed (R. Johnston, private communication).

The application of snubbing units to the pulling of tubing in the 1-atm chamber is being studied (Shell Development Co., private communication). If successful, these units could lead the way toward eliminating the need for surface rigs with derricks.

Remote well reentry using ultrasonics is being developed.[32] When coupled with a television camera, this system could become a powerful subsurface inspection tool.

4.4.4 Recommendations

Most of the above-listed requirements have already been discussed, and recommendations have been made (sect. 3.5.4, 4.2.4).

The testing of drilling BOP's should be extended to the type used during wireline servicing.

Additionally, the development of a reliable pumpdown (TFL) workover and servicing capability, coupled to a statistically based program of preventive maintenance, could minimize many of the problems and virtually eliminate failure-related repairs.

5. TRANSPORTATION OF MEN, EQUIPMENT, AND HYDROCARBONS

This section describes improved stabilization of the workboat; transfer of hydrocarbons to and from tankers; and corrosion, erosion, and location of leaks in pipeline systems.

5.1 Improved Stabilization of Workboat

5.1.1 Requirements

As oil and gas drilling and production operations move farther from shore, the need for routine high-speed transport of men and materials to remote offshore locations will increase. This need

would remain the same in bad weather or could increase dramatically if there were not enough time to avoid a storm due to inadequate weather-prediction capabilities. Reliable transportation of workers is required when a storm or accident has damaged the platform, or a fire or explosion hazard requires evacuation from the platform. In addition, well-control or other material should be available to the platform even in moderately bad weather. When offshore operations expand to new areas such as the Atlantic and Alaskan coasts, the environments will be more severe than those in the Gulf of Mexico and California coast areas.[33] This severity will strain even more the transportation systems now in use.

5.1.2 Equipment in Field Use

Routine high-speed transport of men is supplied by helicopters, which are severely limited in fog or high winds. In these types of weather, conventional boats, which are both slow and uncomfortable, transport men to the oil field. If the seas are rough, the crew might not be in physical condition to work once on board the platform.[34] Most heavy material is routinely transported with the workboat.

In good weather, conventional workboats can transport men and materials on and off the platforms. Although the workboats normally survive fairly heavy seas, there is a safety hazard if they are used in transferring men and materials to and from platforms, due to the large relative motion between the boat and platform. The USGS Events File is a computer-based file of pollution spills and accidents that have occurred during OCS operations in the Gulf of Mexico. The file indicates that drownings from boat sinkings, barges capsizing, or men falling off boats and barges at or near rigs took 21 lives in the period from 1970 to September 1975 (D. W. McDonald and J. R. Griffin, Harry Diamond Laboratories, unpublished data). It is not clear whether a more stable boat could have prevented some of these accidents.

Sometimes the crew is in imminent danger due to such events as severe structural damage to the platform or drill rig caused by fire, explosion, wind, or waves. In such emergencies, the crew uses escape capsules, which protect the occupants from fire on the water and ride slowly and safely through high seas. Because of recent events in the Gulf of Mexico involving the sinking of the jackup Ocean Express,[35] the reliability of this escape system remains a question. Hopefully, it will be cleared up by the U.S. Coast Guard Board of Investigation hearings in New Orleans.

5.1.3 Equipment under Development

The application of two concepts currently being developed would aid in the task of transferring men and material to rigs and platforms in moderate seas. (1) Exxon is working on a motion-compensated crane that will reduce the relative motion between the crane hook and the deck of the boat. (2) The Ryan Ramp attached between boat and platform will be more stable to walk on and stabilize the boat deck by reducing roll.[36] Unfortunately, neither of these devices addresses the problem of high-speed transport of men and material from shore to the platform. In addition, they will not completely solve the problem of collisions between the boat and the platform, caused by their high relative motion, or the problem of men falling from the boats.

A second area of development seems more promising. Several organizations, including the U.S. Navy, have designed semisubmersible ships. A semisubmersible workboat could provide a relatively stable platform, even in rough seas.

The Navy built a prototype stable, semisubmerged platform boat in 1973.[37] It weighs 190 tons and measures 89 ft in length and 45 ft in width. It carries a payload of 10 tons with 18.8 tons of fuel and has an operating range of 350 nautical miles at a cruise speed of 24 knots. Its design permits normal operations in 8-ft waves. A test and evaluation program was initiated in 1975 as part of a large investigation of the small waterplane area twin-hulled (SWATH) concept. An efficient multipurpose ship was designed that is practical from 100 to 15,000 tons and at cruising speeds up to 45 knots. Its purpose is achieved by "placing the greater portion of the ship's bouyant volume below the sea surface and supporting the above surface structure by thin struts which are little affected by wave action. Stability will be exceptional both underway and at rest in sea states up to 7."[37]

In addition to the Navy effort, several private companies have been at work on advanced water transportation concepts. An 85-ft quadhulled catamaran began carrying passengers in 1975 in the Netherlands Antilles. It is conceptually similar to the Navy semisubmerged platform.[37,38] Stability is not affected whether the craft runs at full speed or lies dead in the water. It has a gross weight of 34 tons and a payload of over 10 tons. Maximum speed in 12- to 15-ft seas is 20 knots, and it has a cruise speed of 15 knots with a range of 500 nautical miles with 72 passengers and 3 crew members.

Another development is the Boeing Jetfoil craft, which was introduced to service in both Hong Kong and Hawaii in 1975. "It is a fully submerged foil hydrofoil that employs turbine powered waterjet

propulsion and automatic stabilization and control to enable high speed operations in rough seas."[39] It has a speed of 45 knots at nominal load. However, this craft does not have the stability when not moving that is associated with crafts having catamaran types of hulls.

A new type of high-speed water transport system may compete with the helicopter because of the water transport's possible relative independence of marginal weather conditions, but it would not compete with an escape capsule if there were fire on the water.

5.1.4 Recommendations

Studies are needed of the overall transportation system between land and offshore oil fields, including such oil industry mission requirements as load capacity, speed, and range. Present areas of operations should be considered--the Gulf of Mexico and the Pacific coast--as well as areas where operations will soon begin--the Atlantic and Alaskan coasts. These requirements should be compared to the mission capabilities, stability in typical sea states, and costs of currently used ships, as well as new designs or adaptations of them. For operating in new, more-hostile areas, such as the Atlantic and Alaskan coasts, where little experience is available, it could be of value to study the experience gained in North Sea operations.

Safety should be adequately considered. Accidents resulting in deaths and injuries related to the use of both helicopter and water-surface transportation systems should be studied.

If these studies indicated that a newer type of offshore transportation system would be beneficial, the development of a demonstration craft should be encouraged. This program could be conducted in three steps: prototype design, construction, and test and evaluation.

5.2 Transfer of Hydrocarbons to and from Tankers

5.2.1 Requirements

Due to formation features, harbor conditions, and pollution and safety requirements, the need will increase for offshore transfer of hydrocarbons from production facilities to tankers and from tankers to pipelines to shore. These transfer facilities, like all others associated with the offshore oil industry, must be nonpolluting and safe (minimizing fire and explosion hazards). Along this line, provision for either bad-weather operation or shutdown of the facility must be made.

5.2.2 Equipment in Field Use

At the present time, there are no U.S. facilities for offshore transfer of hydrocarbons. However, U.S. technology has provided many such facilities in other parts of the world.[40]

Currently, offshore rigs and platforms transfer diesel fuel, mud, etc., to and from workboats. The USGS Events File refers to continuing pollution problems with this equipment (D. W. McDonald and J. R. Griffin, unpublished data). All such transfer operations are somewhat similar; it is important to identify the specific causes of small polluting spills associated with transfer equipment now in use, so that similar spills can be avoided in future hydrocarbon transfer operations.

5.2.3 Equipment under Development

Exxon has designed a system for installation off the California coast. It will transfer hydrocarbons from nearby production facilities to a tanker for transport to shore. In addition, similar capabilities are designed into the Exxon SPS.[41]

The U.S. Army has developed and tested equipment for the safe refueling of helicopters and other vehicles at higher rates of flow than are possible by conventional open-port refueling procedures.[42] This equipment and procedure, called "closed-circuit refueling," might be adaptable to the high-speed transfer of hydrocarbons to and from tankers.

5.2.4 Recommendations

Offshore facilities for the transfer of hydrocarbons to and from tankers should be as safe as possible when they are installed. Therefore, the USGS should study the designs of such facilities that are located in other parts of the world. This study should consider safety and pollution experiences and relate these to the differences in environments between the locations of those facilities and areas of interest along the U.S. coasts. The study should define what the state of the art is of the facility designs and what problems are encountered in various environments. Also of use would be a hazards analysis of a facility planned for installation along the U.S. coasts, such as that planned by Exxon along the southern California coast. In addition, the USGS should devise an inspection strategy for these facilities. Finally, if the results of these studies warrant it, appropriate facility design changes should be recommended.

5.3 Corrosion, Erosion, and Location of Leaks in Pipeline Systems

5.3.1 Requirements

To be economical, a pipeline system installed offshore is expected to serve for many years. Over its lifetime, the pipeline must survive erosion by sand and corrosion by transported fluids and salt water. In addition, the system must survive mud slides, storm-generated wave motion, and anchor dragging. If the pipeline does not survive these destructive forces, then the rest of the system must react quickly when the pipeline is ruptured.

Survival of the pipeline system means a prevention or minimization of polluting leaks. This survival requires that the system be designed to eliminate or resist destructive conditions. Another approach would be early detection of the conditions that lead to failure, so that timely corrective actions can be taken. Finally, if a leak should occur, there should be the possibility for fast, effective reaction to correct the situation and minimize the resulting pollution while also minimizing the danger to divers and other personnel.

5.3.2 Equipment in Field Use

Offshore pipeline systems include the pipe, flow and pressure detectors (both onshore and on platforms), and associated safety valves and shutdown system.

The problem of internal sand erosion is minimized by removal of most sand from the hydrocarbon fluid by production separation equipment before the fluid enters the pipeline system. Corrosion is prevented by protective coatings and sacrifical anodes or cathodes.

When the pipeline has been properly designed or modified, it can be inspected for erosion or corrosion by sending a pig through the line periodically.

Check valves prevent the hydrocarbon in the pipeline from adding to a leak or spill caused by the failure of equipment on a production platform. These devices often fail to function properly during periodic inspection testing.[34]

Continuous-leak-detection methods in use can sense relatively large leaks only. Such methods are visually sighting an oil slick or gas bubbles, sensing an unexpected pressure loss in the pipeline, and measuring the flow of fluids into and out of the pipeline system. The pipeline might have to be traced from a platform or other known location to find the exact location of the leak.

5.3.3 Equipment under Development

The USGS is sponsoring an effort to define the technology available for improving mass-flow measurement. The National Aeronautics and Space Administration has been working on satellite-assisted sensing and monitoring of oil slicks.

A new anchoring system developed by the Navy might alleviate some of the problems associated with anchor dragging. The Naval Civil Engineering Laboratory has developed a deep-water, propellant-actuated anchor that can be embedded in sea floors of sand, clay, or rock.[43] The anchor has a holding capacity of 20,000 to 60,000 lb and is functional in water depths from 50 to 20,000 ft.

A process for treating the surfaces of metals and alloys using lasers has been developed by the United Technologies Research Center (E. M. Breinan, private communication).[44] By this technique, called laser skin melting, it is possible to melt a thin layer at the surface while maintaining a cold substrate, resulting in rapid quenching of the molten surface layer into the bulk solid. Cooling rates of up to 10^9°F/s are possible in melt layers of 0.0001-in. thickness in nickel-base alloys.

Specific potential applications of the laser-skin-melting technology include erosion- and wear-resistant coatings, fatigue-resistant surface coatings or treatments, and oxidation-resistant coatings where corrosion is involved. In some cases, surfaces may be modified by laser skin melting of the base material. Where changes in alloy chemistry at the surface are required to obtain the desired properties, alloying elements may be added prior to laser skin melting by a variety of surface deposition techniques and may be melted in during the skin-melting pass. In addition, the modified surface may be more resistant to scale buildup.

The use of various technologies was studied, including acoustics, electromagnetics and radar, infrared, magnetics, and nucleonics, for locating underground obstacles.[45] These obstacles are such man-made objects as lines and tunnels for electrical power, water, gas, sewerage, and communications. If these sensors alone or combined were effective for quickly and inexpensively locating underwater pipelines, then the exact location of offshore pipeline leaks might be located faster than current practice allows. Also, periodic surveys would indicate changes in pipeline location due to such situations as mud slides, wave motion, or anchor dragging. These methods might allow corrective action before a rupture occurs.

A study of leak detection methods in underwater oil pipelines[46] suggests the use of piezoelectric transducers to detect crack propagation within, impact on, or leakage of oil through the pipe wall. These transducers can be spaced as much as 500 ft apart. By timing the arrival of signals caused by impacts such as anchor dragging at two or more sensors spaced along the pipe, the location of the impacts can be determined. Such a system has the advantage of continuous detection capabilities, as opposed to currently used pigs, which are used only periodically. However, piezoelectric transducers cannot sense corrosion or erosion damage, whereas properly instrumented pigs can. Current methods such as mass flow measurement with orifice plates are unable to detect the minute leaks that can be sensed by acoustic methods.

5.3.4 Recommendations

The effort for improved mass flow measurement should be continued. This approach modifies and disrupts the pipeline system least and provides a very good chance of successful application.

A study should be made of the feasibility of using the new anchor system developed by the Navy on ships that tend to be involved in anchor-dragging incidents. Special attention should be paid to the costs involved, which may be prohibitive at $1400 per usage.[43]

The new laser-skin-melt technique should be studied as it could apply to corrosion, erosion, paraffin buildup, and scaling in pipes and safety valves.

Because of the problems with check valves, the use of the laser-skin-melt technique in the fabrication of these valves could be of special interest. In addition, check-valve-design improvements should be studied. If successful designs cannot be found for all field applications, then, where operational conditions preclude the reliable functioning of check valves, the placement of a positively closing valve in series with the check valve should be considered.

A study should be made of how available underground pipeline locating techniques apply to underwater pipelines. The capabilities of such a system should center on fast location of underwater pipelines after a leak has been detected. This capability would minimize both the amount of leakage and the amount of time that personnel are exposed to the environment during this phase of pipeline repair.

Use of acoustic sensors for crack, impact, and leak detection should be studied. Although their implementation and use could prove costly, the possible benefits are great enough to make at least an initial study worthwhile.

6. DATA COLLECTION AND DISTRIBUTION

6.1 Requirements

The need exists for an accurate information base that can be used to define safety and pollution problems related to system or component malfunction or human error. The data making up this information base should reflect both everyday component performance and their performance in emergency or catastrophic situations.

This information should not be proprietary and should be made available to any interested parties.[40,47] This availability can be made possible at a practical cost by putting the information into a computer-based data bank that is accessible by both government and industry. In addition, periodic summary reports should be published. An overall approach of openness would increase public confidence in the safety of offshore operations. It would also provide information needed by those interested in investing time and money to provide better, safer equipment to the oil industry. This information could be used to help decide in which areas their efforts could be most beneficial and likely to succeed.

Any system used to collect the required data should incorporate the following criteria. First, start-up and operational costs should be minimized. Second, there should be a minimum of paper work required of those who collect the data. Third, interference with routine work operations on the drill rigs and platforms should be minimized. Finally, this program should be a joint government-industry operation.

6.2 Present Procedures

The computer-based data bank would gather data that are now reported in a number of different ways. These include the USGS Events File, Safety Alert, and Downhole Safety Valve Failure Mode reports. In the near future, USGS will implement a data collection program called the OCS Safety and Pollution Control Device Failure Reporting and Information Exchange Program. In addition, industry provides data publicly through technical reports and API publications.

6.3 Other Practical Procedures

The Government-Industry Data Exchange Program (GIDEP) is a cooperative activity between Government and industry participants seeking to reduce or eliminate expenditures of time and money by making maximum use of existing knowledge.[48,49] The program provides a means to automatically exchange certain types of technical data essential in the research, development, production, and operational life cycles of systems and equipment.

The program is centrally managed and funded by the Government. Any activity that uses or generates the types of data that GIDEP exchanges may be considered for membership. The program specifically excludes classified and proprietary information.

Participants in GIDEP are provided access to four major data banks.

a. The Engineering Data Bank contains engineering evaluation and qualification test reports; nonstandard parts justification data; parts and materials specifications; descriptions of manufacturing processes; failure analysis data; and other related engineering data on parts, components, materials, and processes. This bank includes a section of reports on specific engineering methodology and techniques.

b. The Failure Rate Data Bank contains failure rate and mode data on parts and components. The data come from field performance and reliability demonstration tests on operational systems and equipment.

c. The Metrology Data Bank contains test-equipment calibration procedures and related metrology engineering data on test systems, calibration systems, and measurement technology.

d. The Failure Experience Data Bank contains GIDEP ALERTS, consisting of objective failure information generated wherever significant problems are identified on parts and materials.

Special services are provided within GIDEP through two unique systems. (1) In the ALERT system, the participant is notified of problem areas related to such things as parts, components, or safety conditions. (2) In the Urgent Data Request system, a GIDEP participant may query all other GIDEP participants on specific problems.

This computer data base has significant potential advantages in distributing the technical data required to design and safely operate offshore facilities. First is its low cost. GIDEP participants are not subject to any fees or assessments. At most, there is a requirement to exchange data like those already in the data banks or to provide cost-avoidance savings information to identify the value of the data to the user.

In addition to low operating costs, large program start-up costs are reduced since GIDEP is already functional and available to both Government and industry. Moreover, if some level of international cooperation is desired in the future, some foreign government participation in GIDEP already exists.

Regarding data collection, it is possible to gather safety-device operational data by having the operator fill out forms that are coded for the subsequent entry of the data into a computer-based data bank. In fact, one industry data-collection program does gather data this way.[50]

There are two drawbacks to this approach. First, since it requires manually filling out forms, it places a paper-work burden on operators in the field. Also, as more data are required, the corresponding increase in paper work may cause the quality of data collected to decrease as shortcuts are taken in fulfilling the paper-work requirements. Second, few or no detailed data are available on component or system performance during abnormal occurrences such as emergency or catastrophic situations.

One method to avoid both of these drawbacks is to utilize the concept of the Federal Aviation Administration's flight recorder.[51] This device, housed in a nearly indestructible box, records aircraft performance parameters continuously. In a catastrophe such as a crash, this box is expected to survive and provide information about the cause of the incident, so that similar situations can be avoided in the future.

After recording safety-related device-performance data on a production platform or drilling rig, the recorder's data could be played back and entered into a computer in any desirable format with a minimum of paper work or other human intervention. In addition, if the recorder survived a fire, explosion, or other catastrophe, it could provide an accurate record of what actually occurred preceding and during the catastrophe. If the recorder were not designed to survive the catastrophe, a constant data communications link to shore would preserve the data for later evaluation. Finally, immediate data output could be made available for use by the operator or an onshore installation via the data communications link.

A disadvantage of this method is that industry might not want it. Without the active cooperation of those operating the platform, no sophisticated equipment could be expected to operate for long in the hostile offshore environment.[52] Also, installation and maintenance costs may be prohibitive.

As another approach to data collection, a portable, hand-held electronic device could be used to record pertinent safety-device performance data. This recording device avoids the high cost and reliability problems associated with the fully automated data-collection system, yet still eliminates the bulk of the paper work required by hand collection.

Such a device should be simple to operate, run on batteries, provide for the input of both analog data (verbal comment) and digital data (coded for direct input to a computer data base), and provide for data playback and editing. The offshore operator would use the device's keyboard to enter digital data in the same format required as if he were manually filling out a coded form. These data would be output to a light-emitting diode (LED) display for the operator to check. The digital data, as well as appropriate verbal comments, could be recorded onto a magnetic tape cassette. Data playback (via the LED display or a speaker) and editing capabilities could be provided for. When data recording was complete, the entire tape could be played back over a telephone data link. The digital data would be directly entered into the computer data base, and the verbal comments would be prepared for keypunch operators to enter into the data base in the traditional manner.

To reduce error sources in the data collection process, this device could visually and verbally prompt the operator, check the format of the digital data for errors, and eliminate the need for keypunching the digital data. Also, such a device would greatly ease the burden on the operator or USGS inspectors who must provide the operational data required both now and in the future. A disadvantage of this approach would be the same as that of filling out data forms by hand; it would provide for safety-device performance data on a periodic basis only.

6.4 Recommendations

To simplify the data distribution aspects of the various USGS programs, the possibility of using the GIDEP system should be fully explored. The feasibility should be studied of using Federal Aviation Administration type of data recorder with data communications links on offshore installations. Also, the portable recording device should be developed and evaluated for use in the data-collection program.

7. SUMMARY AND CONCLUSIONS

7.1 Summary of Recommendations

Table I summarizes the recommendations in terms of fire and explosion, asphyxiation, blowout, rig safety, and pollution. Keywords from each recommendation are used to represent the complete recommendation discussed within the listed sections.

Table II estimates the time necessary in man years to perform the recommended tasks. It does not consider other costs such as equipment or travel, which could be considerable.

TABLE I. RECOMMENDATION SURVEY

Section[a]	Hazard				
	Fire and explosion	Asphyxiation	Blowout	Rig safety	Pollution
Structures	—	—	2.4 Stress alarm 2.4 Environmental loading	2.4 Stress alarm 2.4 Subsurface inspections 2.4 Foul-weather communications 2.4 Environmental loading	2.4 Subsurface inspections 2.4 Environmental loading
Drilling operations	3.2.4 Gas sensors 3.3.4 Testing	3.2.4 Gas sensors 3.2.4 Testing	3.1.4 Surface-to-bit communications 3.1.4 Mud-pulse valve 3.1.4 High-temperature logic 3.3.4 Testing 3.4.4 Computer-assisted drilling 3.4.4 Transducer improvement 3.4.4 Computer-assisted training 3.5.4 Pressure-relief valve	3.3.4 Testing 3.4.4 Computer-assisted drilling 3.4.4 Transducer improvement 3.4.4 Computer-assisted training	3.2.4 Gas sensors 3.2.4 Testing
Subsurface production	4.2.4 Inert atmospheres 4.2.4 Multiple-signature fire detector 4.2.4 Gas sensors 4.3.4 Laser surface treatment 4.3.4 Critical-parts list	4.2.4 Gas sensors 4.2.4 Inert breathable gases 4.2.4 Plug-in or portable life support	4.2.4 Support-vehicle stability 4.3.4 Reservoir-to-surface data transmission	4.2.4 Support-vehicle stability 4.3.4 Laser surface treatment 4.3.4 Impact sensors	4.2.4 Gas sensors 4.2.4 Flowmetering 4.3.4 Critical-parts list 4.3.4 Laser surface treatment 4.3.4 Impact sensors 4.3.4 Critical-parts list
Transportation	5.2.4 Design study 5.2.4 Hazards analysis 5.2.4 Inspection strategy 5.3.4 Laser surface treatment	—	—	5.1.4 Transportation 5.1.4 Demonstration craft 5.2.4 Design study 5.2.4 Hazards analysis 5.2.4 Inspection strategy 5.3.4 Laser surface treatment 5.3.4 Check-valve design	5.2.4 Design study 5.2.4 Hazards analysis 5.2.4 Inspection strategy 5.3.4 Mass flow measurement 5.3.4 Anchor system 5.3.4 Laser surface treatment 5.3.4 Check-valve design 5.3.4 Pipeline location 5.3.4 Acoustic sensors
Data collection	6.4 Use of GIDEP[b] 6.4 FAA[c] recorder 6.4 Portable recorder	6.4 Use of GIDEP 6.4 FAA recorder 6.4 Portable recorder	6.4 Use of GIDEP 6.4 FAA recorder 6.4 Portable recorder	6.4 Use of GIDEP 6.4 FAA recorder 6.4 Portable recorder	6.4 Use of GIDEP 6.4 FAA recorder 6.4 Portable recorder

[a] *Numbers refer to report subsections.*
[b] *Government-Industry Data Exchange Program.*
[c] *Federal Aviation Administration.*

TABLE II. RECOMMENDATION MAN-YEAR ESTIMATE

Section[a]	Time (man year)		
	≤1	1 to 2	>2
Structures	——	2.4 Subsurface inspections	2.4 Foul-weather communications 2.4 Environmental loading 2.4 Stress alarm
Drilling	——	3.2.4 Gas sensors 3.4.4 Transducer improvement 3.4.4 Computer-assisted training 3.5.4 Pressure-relief valve	3.1.4 Surface-to-bit communications 3.1.4 Mud-pulse valve 3.1.4 High-temperature logic 3.3.4 Testing 3.4.4 Computer-assisted drilling
Subsurface production	4.2.4 *Inert breathable gases* 4.2.4 Plug-in or portable life support 4.2.4 Support-vehicle stability 4.2.4 Pollution detectors 4.3.4 Impact sensors	4.2.4 *Inert atmospheres* 4.2.4 Gas detectors 4.2.4 Multiple-signature fire detector 4.2.4 Flowmeter 4.3.4 Reservoir-to-surface data transmission	4.3.4 Laser surface treatment 4.3.4 Critical-parts list
Transportation	5.1.4 Transportation study 5.2.4 Hazards analysis 5.2.4 Inspection strategy 5.3.4 Anchor system 5.3.4 Acoustic sensors	5.2.4 Design study 5.3.4 Mass flow measurements 5.3.4 Check-valve design 5.3.4 Pipeline locator	5.1.4 Demonstration craft 5.3.4 Laser surface treatment
Data collection	6.4 Use of Government-Industry Data Exchange Program	6.4 FAA[b] recorder 6.4 Portable recorder	——

[a] *Numbers refer to report subsections.*
[b] Federal Aviation Administration.

7.2 Conclusions

The offshore petroleum industry has utilized and advanced technology in many areas. Much research has been devoted to making the operations safer and less costly. Whole new regions of the OCS have been or are being prepared for development. The environmental problems off the Alaskan Gulf coast and off the Atlantic coast are of prime concern in this development. As in any such endeavor, resources for technology improvement are finite. Therefore, there will always be additional work that can be done in this area. This report has identified a number of such areas where additional research and development funds could be put to use.

LITERATURE CITED

[1] *H. O. Jans, Pertinent Offshore Experience, Exxon Production Research Co., Houston, TX (May 1975).*

[2] *R. L. Geer, Subsea Production Systems Technology--Where Does It Stand and Where Is It Headed, Erdoel-Erdgas-Zeitschrift, 90. Jg./Offshore-Technik (August 1974), 297.*

[3] *Leonard C. Choate, New Coating Developments, Problems and Trends in the Pipeline Industry, Proceedings of the 1974 NACE Conference (1974).*

[4] *Edwin L. Lowery, Rig Instrumentation System: A New Type of Safety Insurance, Petroleum Engineer (10 January 1975).*

[5] *Army Research Organization--Physics Division, Submillimeter Research: Programs, Plans and Philosophy, Durham, NC (1976).*

[6] *National Oceanic and Atmospheric Administration and Bureau of Land Management Environmental Assessment of the Alaskan Continental Shelf, Program Work Statements, Vol. 6, 7, 8, Boulder, CO (1976).*

[7] *John Scott, North Sea Boom Breeds New Methods, Technology, Petroleum Engineer (30 October 1974).*

[8] *Ivar Foss, Concrete Gravity Structures for the North Sea, Ocean Industry (August 1974), 54.*

[9] *C. A. Bainbridge, Certification of Fixed Steel Platforms in the North Sea, Offshore Technology Conference (1975), 2410.*

[10] *The Guyed Tower--Field Test of a Deepwater Concept for Offshore Structures, Exxon Production Research Co., Grand Isle, LA (March 1975).*

[11] *Ocean Test Structure Technical Plan, Exxon Production Research Co., Houston, TX (October 1975).*

[12] *Adrian A. Pollock, Acoustic Emission, Machine Design (April 1976).*

[13]J. Kim Vandiver, Detection of Structural Failure on Fixed Platforms by Measurement of Dynamic Response, Offshore Technology Conference (1975), 2267.

[14]Olaf Loland and Colin J. Dodds, Experience in Developing and Operating Integrity Monitoring Systems in the North Sea, Offshore Technology Conference (1976), 2551.

[15]W. J. McDonald and C. E. Ward, A Review of Downhole Measurements while Drilling, Sandia Laboratories Report SAND75-7088 (November 1975).

[16]Borehole Telemetry: A Survey of the State-of-the-Art and Projected User Adoption of Borehole Telemetry Systems Providing Down-Hole Measurements while Drilling Services, F. Eberstadt and Co., Inc., New York (20 November 1975).

[17]New Tool Accelerates Directional Surveying, World Oil (October 1975).

[18]M. A. Madonna, Investigation of Environmental Effects on Pure Fluid Amplifiers, Final Report, McDonnell Aircraft Corp., St. Louis, MO, Report No. G102 (1 March 1968).

[19]B. H. Russell, Hazards Analysis of a Mobile Drilling Platform, General Electric Co., Space Division, Houston, TX, Report No. HA-12 [n.d.].

[20]J. L. Holster et al, A Facility for Qualification Testing of Subsurface Safety Valves, ASME 75-PET-14 (September 1975).

[21]Lee Tuck, Mass Measurement at Ekofisk, Petroleum Engineer (October 1975).

[22]Travis Brown, 10 Years from Now: What Will We Record and How Will We Do It? Drilling-DCW (October 1975).

[23]D. H. Ward et al, A Computer Controlled System for Automated Racking of Pipe on Drilling Vessels, Offshore Technology Conference (May 1975), 2154.

[24]E. E. Horton, Production System Developed for Deep Sea Floor Uses, World Petroleum, 22 (1970).

[25]J. A. Burkhardt, A Progress Report Test of Submerged Production System, Proceedings of the 1975 Society of Petroleum Engineers Conference (1975).

[26]A. T. Chatas and E. M. Richardson, The Multiple-Well Manifold/Production Station, Proceedings of the 1975 Petroleum Mechanical Engineering Conference (1975).

[27]K. Kirkland and J. Johnson, The Production Riser System for the Argyll Field, Proceedings of the 1975 Offshore Technology Conference (1975).

[28] G. H. Fahlman, Safety Characteristics of Lockheed's Subsea Production System, Proceedings of the 1974 Offshore Technology Conference (1974).

[29] W. D. Loth, J. A. Burkhardt, and T. A. Covellone, Template Structure and Installation--A Subsystem of the Submerged Production System, Proceedings of the 1976 Offshore Technology Conference (1976).

[30] W. H. Silcox, Technical Capabilities in Offshore Completion and Workover Operations to Maximize Safety, Proceedings of the 1972 Offshore Technology Conference (1972).

[31] Ultra-Sensitive Pressure Gauge Solves Many Field Problems, World Oil (1976), 76.

[32] D. T Hazelwood, Acoustic Re-entry Concepts for Subsea Exploration Drilling and Production Platforms, Proceedings of the 1975 Offshore Technology Conference (1975).

[33] Final Environmental Impact Statement, OCS Proposed Oil & Gas Leasing in the Northern Gulf of Alaska, Sale No. 39, Vol. 1, U.S. Department of Interior, Bureau of Land Management (1976).

[34] W. B. Bleakley, Where Offshore Production Stands Today, The Oil and Gas Journal (6 May 1974).

[35] Survival Bulletin No. 011, Whittaker Corp. (30 April 1976).

[36] Unique Ramp Offers More Stable Surface at Sea and Reduces Boat's Roll, Ryan Ramp, Inc., Harahan, LA (1976).

[37] Ocean Engineering, Ocean Technology Department, Naval Undersea Center, NUC TP 278, Rev. 1 (January 1975).

[38] B. Kocivar, Quad-Hulled Catamaran Tames Rough Seas, Popular Science (May 1976).

[39] W. M. Schultz, Jetfoil--A Potential High Speed Marine Offshore Support Vehicle, Offshore Technology Conference (May 1976), 2632.

[40] U.S. Must Turn to the Sea, Ocean Industry (September 1973).

[41] W. E. Gammage et al, Marine Production Riser--A Subsystem of the Submerged Production System, Offshore Technology Conference (May 1976), 2525.

[42] Wayne E. Studebaker, Closed-Circuit Refueling (CCR), U.S. Army Mobility Equipment Research and Development Command Report No. 2110 (September 1974).

[43] CEL 20K Propellant-Actuated Anchor, Naval Civil Engineering Laboratory Techdata Sheet 75-16 (July 1975).

[44] Passing Laser Beam Forms Metallic Glass, Machine Design (April 1976).

LITERATURE CITED (Cont'd)

[45]D. C. Gates and R. A. Armistead, The Use of Advanced Technologies for Locating Underground Obstacles, National Technical Information Service NTIS PB-237-690 (August 1974).

[46]P. A. Jackson, Leak Detection in Underwater Oil Pipelines, National Maritime Research Center, COM-73-11776 (September 1973).

[47]Outer Continental Shelf Resource Development Safety: A Review of Technology and Regulation for the Systematic Minimization of Environmental Intrusion from Petroleum Products, Marine Board, National Academy of Engineering (December 1972).

[48]Program Summary, Government-Industry Data Exchange Program (October 1974).

[49]R. M. Jacobs, Data Collection as a Tool in Designing for Product Safety, ASME 75-SAF-4 (May 1975).

[50]J. H. Ruppel and W. I. Cole, Application of Computer Techniques to Offshore Operations in Compliance with OCS Orders 5, 8 and 9, Offshore Technology Conference (1973), 1753.

[51]D. E. Kash et al, Energy under the Oceans, University of Oklahoma Press, Norman, OK (1973).

[52]Bud Dixon et al, Drilling Recording Yesterday—Today —Tomorrow, Drilling—DCW (October 1975).